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The effect of leadtime on effectiveness at Naval Supply Center, Oakland, California

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THESIS

THE EFFECT OF LEADTIME ON EFFECTIVENESS
AT
NAVAL SUPPLY CENTER, OAKLAND, CALIFORNIA

by

Robert K. Scott

December, 1990

Thesis Advisor: Dan Trietsch

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However, this thesis did determine that forecasted leadtime closely predicted the probability that an item would achieve a given net effectiveness in the six month time period following the date of the replenishment requisition. Even better correlators with the probability of achieving a given net effectiveness were observed leadtime and the ratio of observed leadtime to forecasted leadtime.

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The Effect of Leadtime on Effectiveness
at
Naval Supply Center, Oakland, California

by

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Submitted in partial fulfillment
of the requirements for the degree of

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ABSTRACT

The area of research was to determine a mathematical relationship between the leadtimes of replenishment requisitions and the subsequent net effectiveness of the corresponding items at a military inventory stock point. This thesis determined that leadtime did not predict actual net effectiveness well.

However, this thesis did determine that forecasted leadtime closely predicted the probability that an item would achieve a given net effectiveness in the six month time period following the date of the replenishment requisition. Even better correlators with the probability of achieving a given net effectiveness were observed leadtime and the ratio of observed leadtime to forecasted leadtime.

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I. INTRODUCTION

A. PROJECT DESCRIPTION

The United States Navy divides inventory management of spare parts and consumable material into three levels:

- Wholesale (induction of material from vendors into the system).
- Intermediate (geographic area support by activities holding inventories of material requisitioned from the wholesale level, usually stock points but also certain other activities).
- Retail (end use of material by consumer commands which requisition material from the intermediate level).

This flow of material from the wholesale level, to the intermediate, and finally to the retail level takes time. The amount of time elapsed from when an activity submits its requisition to the next higher level until it receives the material is termed leadtime or order and shipping time. Leadtimes vary, both by item and by different requisitions for the same item.

This thesis focused on leadtimes at the intermediate level, specifically the stock point Naval Supply Center, Oakland, CA (NSC Oakland). Stock point management and higher authority used several measures of effectiveness to gauge the activity's performance during the time of this thesis (1989 and 1990). The two measures of effectiveness used which most closely measured performance by inventory managers were Gross

Effectiveness and Net Effectiveness. Gross Effectiveness is the ratio of issues immediately made by the activity to total requests for material of all types, regardless if the activity carries the material. Net Effectiveness, on the other hand, is the ratio of issues immediately made by the activity to requests for material that the activity normally carries. Net Effectiveness more closely measures the performance of item managers, who have responsibility for managing material which the activity has decided to carry. Gross and Net Effectiveness are identical for any sample which contains only carried items, such as this study. Further information concerning inventory management procedures may be found in Navy Fleet Material Support Office (FMSO) Instruction 4400.12J [Ref. 1] and Naval Supply Systems Command (NAVSUP) Publication 553 [Ref. 2].

The area of research was to determine a mathematical relationship between Leadtime (LT), the independent variable, and Net Effectiveness (NET), the dependent variable, at an intermediate level, military supply center. The study determined that Forecasted Leadtime (LTF) did not predict NET directly. However, the study did determine that LTF closely predicted the probability that an item would achieve a given NET. Further, even better correlators with the probability an item would achieve a given NET were Observed Leadtime (LTO) and the relationship between the ratio of LTO to LTF, defined here as Leadtime Index (LT INDEX). Selected categories of

national stock numbered (NSN) items stocked by NSC Oakland composed the research sample.

Traditionally, managers in the military have viewed LT from the perspective of minimizing it in order to reduce investment costs of material on order. While this is indeed proper given the existing system incentives, this study viewed LT from the perspective of what effect it has on NET. Intuitively, LTs longer than forecasted should delay receipt of due-in material, perhaps long enough for the on-hand quantity to decrease to zero (or to a certain threshold below which low priority requisitions would not be filled). Item managers have some control over LT, through choice of replenishment requisition priority, mode and priority of transportation, choice of alternate sources of supply, and expediting efforts. These reasons warrant statistical analysis of a possible relationship between LT and NET.

B. RESEARCH QUESTIONS

The primary research question is: What mathematical relationships do LTF, LTO, and LT INDEX have on subsequent NET? Secondary questions are:

- How does the replenishment algorithm compute LTF?
- For a sample of replenishments, how precise is LTF compared to LTO?
- For a sample of replenishments, what statistical distribution(s) describes LTF, LTO, LT INDEX, and subsequent NET for the corresponding NSNs?

- Using regression analysis, what equations best fit the possible relationships between LTF, LTO, and LT INDEX with NET?
- Is there a statistically significant relationship of NET with respect to time measured since the date of the replenishment action?

C. SCOPE, LIMITATIONS, AND ASSUMPTIONS

The study was not an exhaustive investigation of possible factors influencing NET. The study selected a sample of replenishments over a relatively long time period compared to average LT. By application of the central limit theorem from statistics, the additive effects of other factors tended to be normally distributed. Other factors which influenced NET included:

- changing demand trends (long term increase or decrease).
- demand fluctuations (short term, non-predictable changes).
- the ratio of on-hand to due-in quantities at the time of replenishment (a lower ratio means relatively more material is due-in and therefore not immediately available for issue).
- non-optimum replenishment quantities due to either failure of assumptions of the replenishment algorithm or insufficient funding.

These factors are beyond the scope of this thesis.

This presentation assumes a basic understanding of:

- the United States Navy's supply system at the retail intermediate level [Ref. 1] and [Ref. 2].
- elementary statistics, including simple linear regression analysis with transformations [Ref. 3].

D. METHODOLOGY SYNOPSIS

The study selected a sample of non-repairable NSNs having replenishment actions and for each replenishment action computed:

- LTF.
- LTO.
- LT INDEX.
- NET for each NSN monthly for six months after the date of that NSN's replenishment.

Regression analysis yielded only poor mathematical relationships of NET as functions of LTF, LTO, or LT INDEX. However, binomial transformations of NET, where values of NET greater than or equal to 85% were assigned the value of one and values less than 85% were assigned zero, yielded probability distribution functions as functions of LTF, LTO, and LT INDEX with values of the sample coefficients of determination ("r^2") of 0.866, 0.89, and 0.94 respectfully.

E. LITERATURE REVIEW

Computer searches of the holdings of Defense Technical Information Command, Defense Logistics Studies Information Exchange, and the Naval Postgraduate School library yielded no previous studies of the effect of LT on NET at a military stock point. Perry, Silins, and Embry did study a related topic, procurement leadtime of material contracted by selected inventory control points from vendors [Ref. 4]. They

concluded that excessive procurement leadtimes adversely affect the effectiveness and cost of the military's supply systems.

F. ORGANIZATION OF THE STUDY

Following a description of the procedures for inventory management at NSC Oakland and development of the concepts of NET and LT, I will briefly outline the statistical and regression procedures used. Then I will describe how the data was generated and provide appropriate summaries and charts. Finally, I will apply statistical and regression procedures to the data and then summarize, draw conclusions, and make recommendations.

G. DEFINITIONS

- National Stock Number (NSN) is a 13 digit number used by the United States Department of Defense which uniquely identifies most items stocked by the military supply systems.

- Net Effectiveness (NET) is the percentage of the number of issues made from stock on hand divided by the number of total requests for stocked items during a specified time period.

- Leadtime Forecasted (LTF) is computed at NSC Oakland by an exponential smoothing formula which sums the products of the previous quarter's LTF multiplied by 0.8 and the current quarters LTO multiplied by 0.2 [Ref. 1: Enclosure (1), p. III-4].

- Leadtime Observed (LTO) is the time from when the item manager (or the supporting computer programs) makes the replenishment decision to the time when the item is available for issue to customers.

- Leadtime Index (LT INDEX) is the ratio of leadtime observed to leadtime forecasted.

- Retail Intermediate Level is that part of the Navy's supply system which provides supply support to a specified geographic area of end user, or consumer, commands. Retail intermediate level commands are generally stock points which in turn replenish their inventories by requisitioning material from the wholesale level, or inventory control points. NSC Oakland functioned as a retail intermediate level command for the NSNs in this study.

II. BACKGROUND OF THE PROBLEM

A. INVENTORY MANAGEMENT

A detailed description of the inventory management procedures used at NSC Oakland is beyond the scope of this study. Fleet Material Support Office (FMSO), Mechanicsburg, PA., developed and standardized these inventory procedures for use by all U.S. Naval supply centers, including NSC Oakland [Ref. 1]. This instruction provides a summary of inventory management procedures used by NSC Oakland for intermediate level consumable inventories. Additionally, Naval Supply Systems Command (NAVSUP) sponsored a textbook which is a basic guide to requirements determination in the Navy, including the retail intermediate level [Ref. 2].

From the viewpoint of an inventory manager, there are two main types of supply systems:

- Stock is pulled, or requested, from other activities.
- Stock is pushed from other activities, without request from the receiving activity.

The first method requires decision making at the receiving activity, while the second method places the decision making at the sending activity. This study selected only NSNs which NSC Oakland managed by the first, or pull, method and which required transportation. Some NSNs stocked by NSC Oakland were managed by other activities using the push method. This

study specifically omitted any NSN which had any quantity managed by other activities. The purpose of this constraint was to study NSNs which could not be replenished by stock carried at NSC Oakland although managed by an external activity. Leadtime for such an item would be only the sum of the electronic transmission time required for NSC Oakland's requisition to the managing activity, the managing activity's computer time to process the requisition, and the transmission time of the issue back NSC Oakland. This thesis studied NSNs which required transportation from another activity to NSC Oakland. These preclusions caused the bulk of the studied NSNs to be either Navy cognizance 9Q items (general office supplies procured by General Services Administration), or cognizance 9V items (Air Force procured material).

B. THE REPLENISHMENT DECISION

Basically, NSC Oakland used a minimum-maximum inventory model. When issues and other losses deplete on-hand plus due-in stock to below a certain level (the minimum), the supporting computer program generated a recommended replenishment to bring the inventory position up to the requisitioning objective (the maximum). The length of time from the replenishment decision to the receipt, stowage, and availability for issue of the incoming material was the leadtime. If average demand for material remained constant, increasing leadtimes would cause on-hand quantities to

decrease below forecasted levels. In turn, decreasing actual levels to below forecasted levels increased the risk of stocking out. This study attempted to find a statistical relationship between varying leadtimes and the risk of stocking out.

III. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

A. REVIEW OF PERTINENT STUDIES

Computer searches of Defense Technical Information Command, Defense Logistics Studies Information Exchange, and the Naval Postgraduate School library yielded no previous studies of the effect of LT on NET at a stock point. Two studies found did consider leadtimes, but were not directly related to stock points.

Perry, Silins, and Embry studied procurement leadtime of material contracted by selected inventory control points from vendors [Ref. 4]. They concluded that excessive procurement leadtimes adversely affect the effectiveness and cost of the military's supply systems, but they did not attempt to quantify the effect or cost.

Another study by Price analyzed in-transit leadtimes for material incoming to an Air Force repair depot [Ref. 5]. He concluded that shorter leadtimes and leadtimes with less variance would improve material availability at the maintenance depot.

B. NET EFFECTIVENESS

Historically, item managers have been rated based on their ability to fill incoming requisitions from on-hand stock. The two measures of effectiveness which attempt to rate this

performance directly are Gross Effectiveness (GROSS) and Net Effectiveness (NET). The definition of GROSS is the percentage of the number of issues made divided by the total number of incoming requisitions:

GROSS = (ISSUES / TOTAL REQUISITIONS) X 100

NET is similar but with the important difference that the denominator is the number of requisitions for material actually carried by the activity, not the total of incoming requisitions for both carried and not carried material:

NET = (ISSUES / CARRIED REQUISITIONS) X 100

NSC Oakland's goals for GROSS and NET were 70% and 85% respectively during the period of this study. Because NSC Oakland carried all NSNs studied, this study focused on NET.

C. LEADTIME AND LEADTIME INDEX

1. Leadtime (LT)

This thesis defined LT as the time from the replenishment decision to the time the material was available for issue to customers. This time included:

- preparation of the replenishment requisition.
- transmittal to the supplying activity.
- the supplying activity's processing.
- material transportation.
- the receiving activity's receipt processing.
- stowage of the material.

For readers familiar with supply center terminology, LT was defined as the sum of order and shipping time, receipt processing time, and time to stow.

2. Forecasted Leadtime (LTF)

NSC Oakland computed LTF for the NSNs in this study with supporting computer software (Uniform Automated Data Processing System - Stock Points (UADPS-SP) program D-UB39, "Quarterly and Random Demand Update and Levels Computation"). This program applied exponential smoothing to the old LTF and the average of the current quarter's LTO to compute the forecast for the next quarter according to this formula:

$$LTF_{n+1} = (0.8 \times LTF_n) + (0.2 \times AVER\ LTO_n)$$

Program D-UB39 constrained LTF to less than or equal to two months for continental U.S. activities including NSC Oakland [Ref. 1, Encl. (1), p. III-4].

3. Observed Leadtime (LTO)

For this thesis, manual computation of the difference between stow date and requisition date yielded LTO. Microfiche summaries of the "Receipt Due History" file provided the raw data.

4. Leadtime Index (LT INDEX)

This thesis defined LT INDEX is the ratio of LTO to LTF (as of the date of the replenishment) for that specific replenishment:

$$LT\ INDEX = LTO\ /\ LTF$$

For example, if LTO were three months and LTF were two months, then LT INDEX would be 1.5.

LT INDEX was useful in two ways:

- It was a measure of how accurately LTF predicted LTO.
- It allowed comparison of leadtimes of NSNs with different LTFs.

The importance of this measure of effectiveness was that while LTO for two NSNs may have been identical, the first NSN probably had a different LTF than the second. If the replenishment algorithm assumed a LTF of two months for the first NSN but one month for the second, then a LTO of two months was on target for the first NSN but risked stocking out for the second.

IV. METHODOLOGY AND DATA

A. NATIONAL STOCK NUMBER (NSN) SELECTION

The study required each NSN selected to have the following characteristics:

- A known LTF as of the date of the replenishment decision.
- Submission of a valid replenishment requisition.
- Receipt of the replenishment requisition.
- Recorded demand during the period from the date of the replenishment requisition to six months after that date.
- No wholesale stock of the same NSN at NSC Oakland.
- High and low inventory points set by demand rather than by constraints.
- Ability of NSC Oakland to replenish at will without permission from other activities.

These characteristics caused most NSNs selected to be general office supplies centrally procured for the Federal government by General Services Administration (GSA) and material procured for the Department of Defense by the Air Force. The final selection of an NSN depended on whether LTF was available.

B. LEADTIME FORECASTED (LTF)

The limiting factor in selecting NSNs for this study was the existence of historical data containing LTF as of the date of a replenishment. Although program UADPS-SP D-UB39

"Quarterly and Random Demand Update and Levels Computation" computed LTF each quarter, the program overwrote the LTF data field on the Master Stock Item Record (MSIR). Therefore, no historical record existed for LTF older than one quarter. However, a hard copy exception listing of program UJ02 "Stratification" did list LTF for certain NSNs. NSC Oakland ran program UJ02 semiannually and kept the exception listings in file. The exception criteria for this listing were any of the following fields greater than or equal to $10,000:

- Value on Hand.
- Value of Due-In.
- Value of Back Orders.
- Value of Planned War Reserve Stock.
- Value of Quarterly Demand.
- Value of Numerical Stock Objective Quantity.

Stratification exception listings dated 26 March 1989, 27 September 1989, and 23 March 1990 yielded 1,351 NSNs with computed LTF. Subject to the two month maximum constraint noted above, the computed LTF shown on the exception listing was valid for approximately 90 days until the next stratification run. Therefore, all replenishment requisitions during this 90 day period used the computed, constrained LTF. For information purposes, Figure 1 contains a histogram and descriptive statistics for raw, unconstrained LTF.

```
                    LEADTIME, FORECASTED, RAW

Histogram:

N = 333
Each * represents from 1 to 5 observations.
Midpoint  Count
  0.5       6   **
  1.0     187   **************************************
  1.5     105   *********************
  2.0      20   ****
  2.5      10   **
  3.0       1   *
  3.5       2   *
  4.0       0
  4.5       0
  5.0       0
  5.5       2   *

Descriptive Statistics:

     N      MEAN    MEDIAN    TRMEAN     STDEV    SEMEAN
   333    1.2955    1.2000    1.2351    0.5336    0.0292

   MIN       MAX        Q1        Q3
0.4000    5.6000    1.0000    1.4000
```

Figure 1 Summary of Raw Leadtime, Forecasted

Figures 2 and 3 provide descriptive statistics and a frequency graph of constrained LTF versus months. Members of the gamma distribution family fit the observed frequency distributions for LTF, LTO, and LT INDEX. The gamma distribution that best fit LTF was:

$$FREQ = 84\ LTF^{0.77}e^{-LTF}$$

Figure 2 also contains a plot of this equation with a plot of LTF lagged 0.8 months to superimpose the two plots. The regression sample coefficient of determination ("r^2") for this transformation was 0.911 over the domain (0 <= X <= 1.2). The chi-square test for this approximation indicated that with alpha equal to 5% there was not sufficient evidence to reject the null hypothesis that the gamma function approximated the actual data.

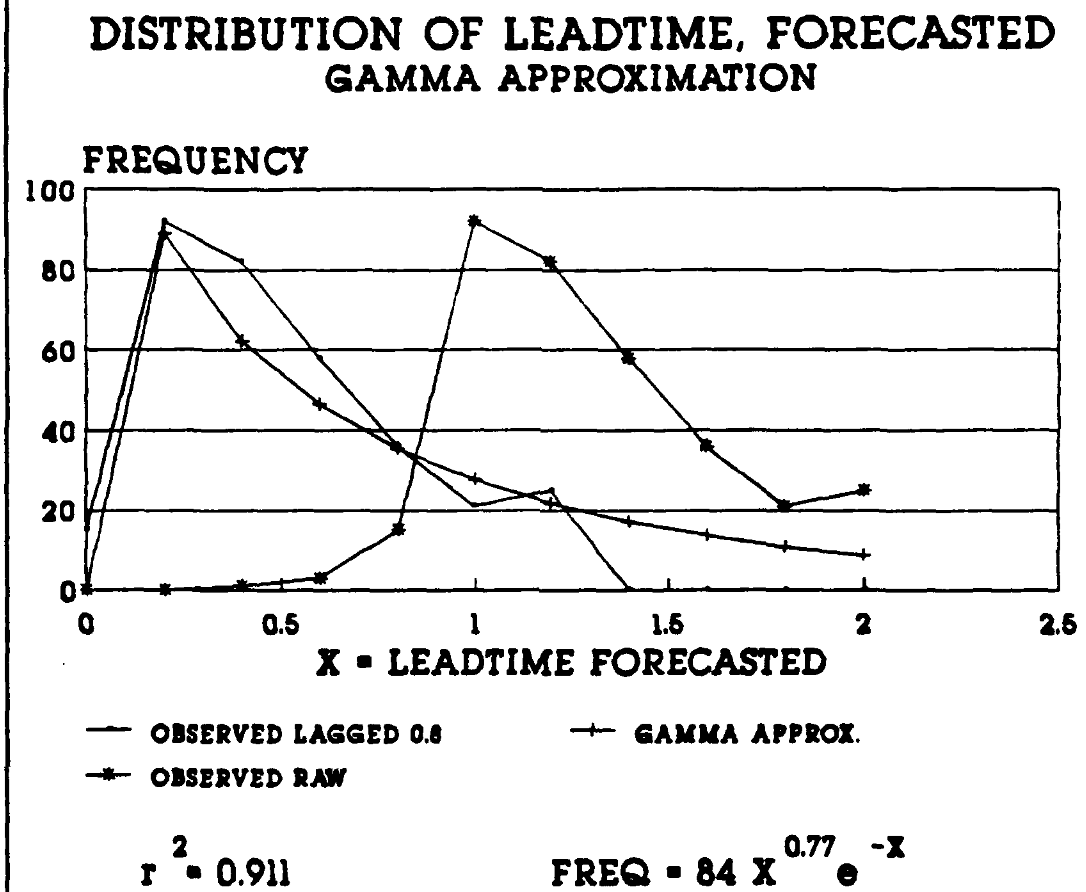

Figure 2 Leadtime Forecasted Approximation

Descriptive Statistics:

N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN
333	1.2468	1.2000	1.2334	0.3372	0.0185

MIN	MAX	Q1	Q3
0.4000	2.0000	1.0000	1.4000

Figure 3 Summary of Leadtime Forecasted

C. LEADTIME OBSERVED (LTO)

NSC Oakland produced a monthly microfiche summary titled "Receipt Due History List" which listed all receipt related transactions during that month. This list contained stow date and requisition date. Each NSN obtained from the stratification exception listing was researched on each monthly "Receipt Due History List" to identify requisitions dated less than 90 days after the date of each of the stratification runs. After noting the stow date and the requisition date, subtraction of these two dates yielded LTO for each NSN. Some NSNs had multiple replenishment requisitions and/or receipts. This study considered each replenishment or receipt to be a separate data point and computed subsequent NET for each. *Figures 4 and 5 contain* descriptive statistics and a frequency plot for LTO. The gamma distribution that best fit LTO was:

$$FREQ = 640\ LTO^{0.000001} e^{-LTO}$$

The "r^2" value was 0.997. The chi-square test for this approximation indicated that with alpha equal to 5% there was not sufficient evidence to reject the null hypothesis that the gamma function approximated the actual data.

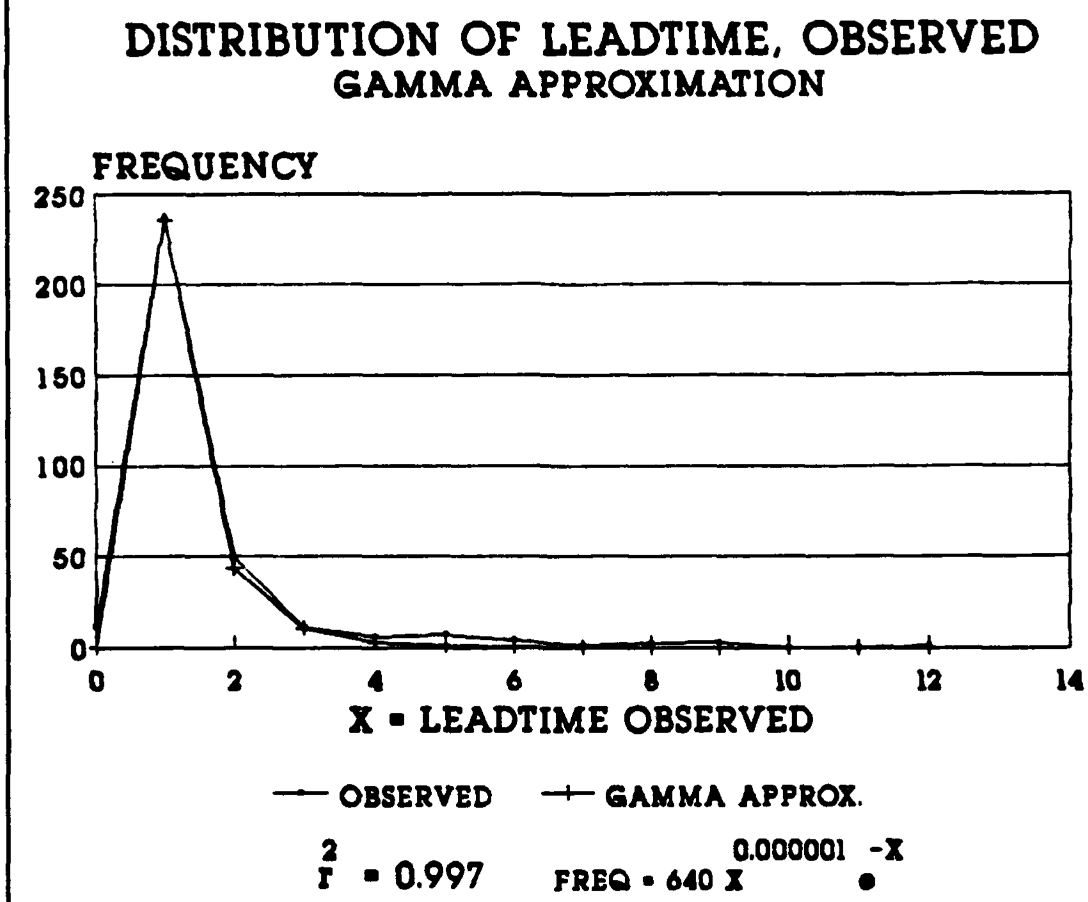

Figure 4 Leadtime Observed Approximation

Descriptive Statistics:

N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN
333	1.4198	1.0000	1.1699	1.5086	0.0827
MIN	MAX	Q1	Q3		
0.1000	12.0000	0.7000	1.5000		

Figure 5 Summary of Leadtime Observed

D. LEADTIME INDEX (LT INDEX)

Dividing LTO by LTF provided LT INDEX for each NSN. Figures 6 and 7 contain descriptive statistics and a frequency plot for LT INDEX. The gamma distribution function that fit LT INDEX with an "r^2" of 0.920 was:

$$FREQ = 232\ (LT\ INDEX)^{1.001} e^{-(LT\ INDEX)}$$

The chi-square test for this approximation indicated that with alpha equal to 5% there was not sufficient evidence to reject the null hypothesis that the gamma function approximated the actual data.

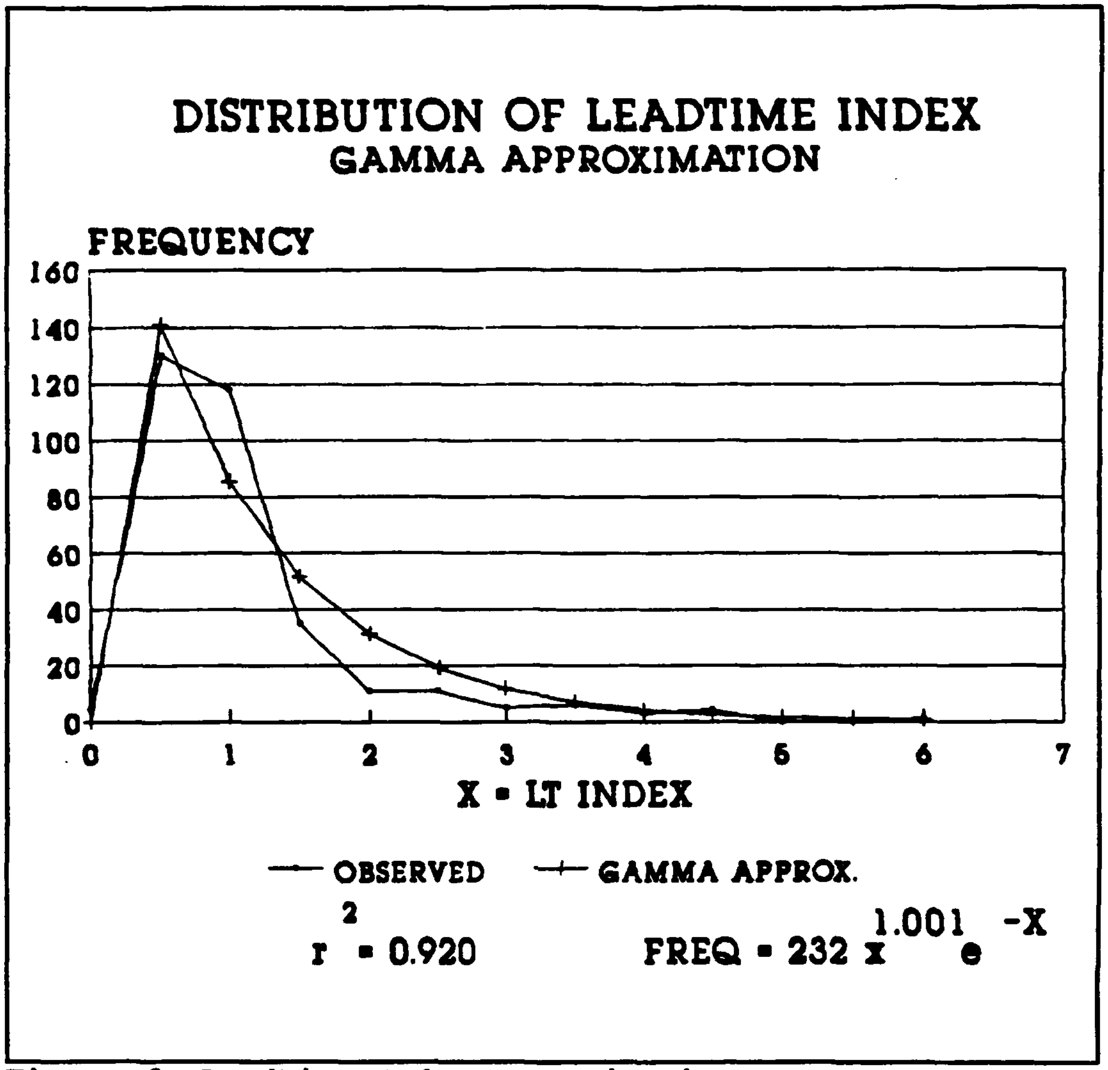

Figure 6 Leadtime Index Approximation

Descriptive Statistics:

N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN
333	1.1738	0.8462	1.0078	1.0884	0.0596

MIN	MAX	Q1	Q3
0.1250	7.2564	0.5963	1.2132

Figure 7 Summary of Leadtime Index

E. NET EFFECTIVENESS (NET)

Another microfiche listing produced by NSC Oakland was a monthly listing of "Transaction Ledger On Disk" entries. This listing provided a monthly record of incoming customer demands, issues (ISS) from NSC Oakland's warehouses to meet those demands, and referrals (REF) by NSC Oakland to other activities when the material was not available for issue. Starting with the month immediately following the replenishment requisition date, NET was computed by month for six months according to the formula:

$$NET = ISS / (ISS + REF)$$

All summary computations of NET, such as NET computed for all six months in aggregate, used the sum of total issues and the sum of total referrals. The alternative, using an average of all individual NSN NETs, would have weighted all NSNs equally vice all customer requisitions. Figures 8 through 13 provide descriptive statistics for each of the first through sixth months following a replenishment requisition.

```
        NET, FIRST MONTH AFTER REQUISITION DATE

Histogram:

N = 282    (Omitted, no value observations = 51)
Each * represents from 1 to 5 observations.
Midpoint    Count
   0.0        26    ******
   0.1         1    *
   0.2         2    *
   0.3        13    ***
   0.4         6    **
   0.5        15    ***
   0.6         6    **
   0.7        15    ***
   0.8        11    ***
   0.9        12    ***
   1.0       175    ***********************************

Descriptive Statistics:

      N       OMIT       MEAN     MEDIAN     TRMEAN      STDEV
    282         51     0.7889     1.0000     0.8208     0.3329

 SEMEAN        MIN        MAX         Q1         Q3    AGGNET[a]
 0.0198     0.0000     1.0000     0.6670     1.0000      0.836

([a] computed using total issues and referrals)
```

Figure 8 Summary of NET, First Month

NET, SECOND MONTH AFTER REQUISITION DATE

Histogram:

```
N = 264   (Omitted, no value observations = 69)
Each * represents from 1 to 5 observations.
Midpoint  Count
   0.0     17  ****
   0.1      0
   0.2      3  *
   0.3     10  **
   0.4      5  *
   0.5     15  ***
   0.6      3  *
   0.7     10  **
   0.8     10  **
   0.9      6  **
   1.0    185  *************************************
```

Descriptive Statistics:

N	OMIT	MEAN	MEDIAN	TRMEAN	STDEV
264	69	0.8330	1.0000	0.8694	0.3022

SEMEAN	MIN	MAX	Q1	Q3	AGGNET[•]
0.0186	0.0000	1.0000	0.7500	1.0000	0.855

([•] computed using total issues and referrals)

Figure 9 Summary of NET, Second Month

```
NET, THIRD MONTH AFTER REQUISITION DATE

Histogram:

N = 245   (Omitted, no value observations = 88)
Each * represents from 1 to 5 observations.
Midpoint   Count
   0.0       14  ***
   0.1        2  *
   0.2        1  *
   0.3        4  *
   0.4        4  *
   0.5       19  ****
   0.6        3  *
   0.7        5  *
   0.8        8  **
   0.9        6  **
   1.0      179  ************************************

Descriptive Statistics:

      N        N*      MEAN    MEDIAN    TRMEAN     STDEV
    245        88    0.8514    1.0000    0.8896    0.2880

 SEMEAN       MIN       MAX        Q1        Q3   AGGNET[a]
 0.0184    0.0000    1.0000    0.8785    1.0000     0.885

([a] computed using total issues and referrals)
```

Figure 10 Summary of NET, Third Month

```
            NET, FOURTH MONTH AFTER REQUISITION DATE

Histogram:

N = 220   (Omitted, no value observations = 113)
Each * represents from 1 to 5 observations.
Midpoint   Count
   0.0        9   **
   0.1        0
   0.2        4   *
   0.3       11   ***
   0.4        6   **
   0.5        9   **
   0.6        2   *
   0.7        4   *
   0.8        9   **
   0.9        4   *
   1.0      162   *********************************

Descriptive Statistics:

     N        N*      MEAN    MEDIAN    TRMEAN     STDEV
   220       113    0.8525    1.0000    0.8898    0.2836

SEMEAN       MIN       MAX        Q1        Q3   AGGNET@
0.0191    0.0000    1.0000    0.8570    1.0000     0.869

(@ computed using total issues and referrals)
```

Figure 11 Summary of NET, Fourth Month

NET, FIFTH MONTH AFTER REQUISITION DATE

Histogram:

```
N = 226   (Omitted, no value observations = 107)
Each * represents from 1 to 5 observations.
Midpoint   Count
   0.0       15  ***
   0.1        1  *
   0.2        0
   0.3        2  *
   0.4        1  *
   0.5       17  ****
   0.6        1  *
   0.7       12  ***
   0.8       11  ***
   0.9        8  **
   1.0      158  ********************************
```

Descriptive Statistics:

N	N*	MEAN	MEDIAN	TRMEAN	STDEV
226	107	0.8503	1.0000	0.8881	0.2853

SEMEAN	MIN	MAX	Q1	Q3	AGGNET[*]
0.0190	0.0000	1.0000	0.8000	1.0000	0.848

([*] computed using total issues and referrals)

Figure 12 Summary of NET, Fifth Month

NET, SIXTH MONTH AFTER REQUISITION DATE

Histogram:

N = 219 (Omitted, no value observations = 114)
Each * represents from 1 to 5 observations.

Midpoint	Count	
0.0	14	***
0.1	0	
0.2	1	*
0.3	7	**
0.4	2	*
0.5	7	**
0.6	1	*
0.7	14	***
0.8	14	***
0.9	4	*
1.0	155	*******************************

Descriptive Statistics:

N	N*	MEAN	MEDIAN	TRMEAN	STDEV
219	114	0.8491	1.0000	0.8881	0.2890

SEMEAN	MIN	MAX	Q1	Q3	AGGNET[*]
0.0195	0.0000	1.0000	0.8000	1.0000	0.860

([*] computed using total issues and referrals)

Figure 13 Summary of NET, Sixth Month

Figures 14 and 15 provide descriptive statistics and a frequency plot for the aggregate six month period following replenishments. The frequency distribution that best fit was this power function:

$$FREQ = 126\ NET^{9.1} + 14$$

The value of "r^2" for this transformation was 0.955. The chi-square test for this approximation indicated that with alpha equal to 5% there was sufficient evidence to reject the null hypothesis that the gamma function approximated the actual data. However, the errors in approximation in the NET interval (0 <= NET <= 0.5) were sufficient to cause the chi-square test value to exceed the published value for alpha equal to 5% and degrees of freedom equal to 10. Considering the high value of "r^2" for this approximation, the equation was useful in the interval (0.6 <= NET <= 1.0).

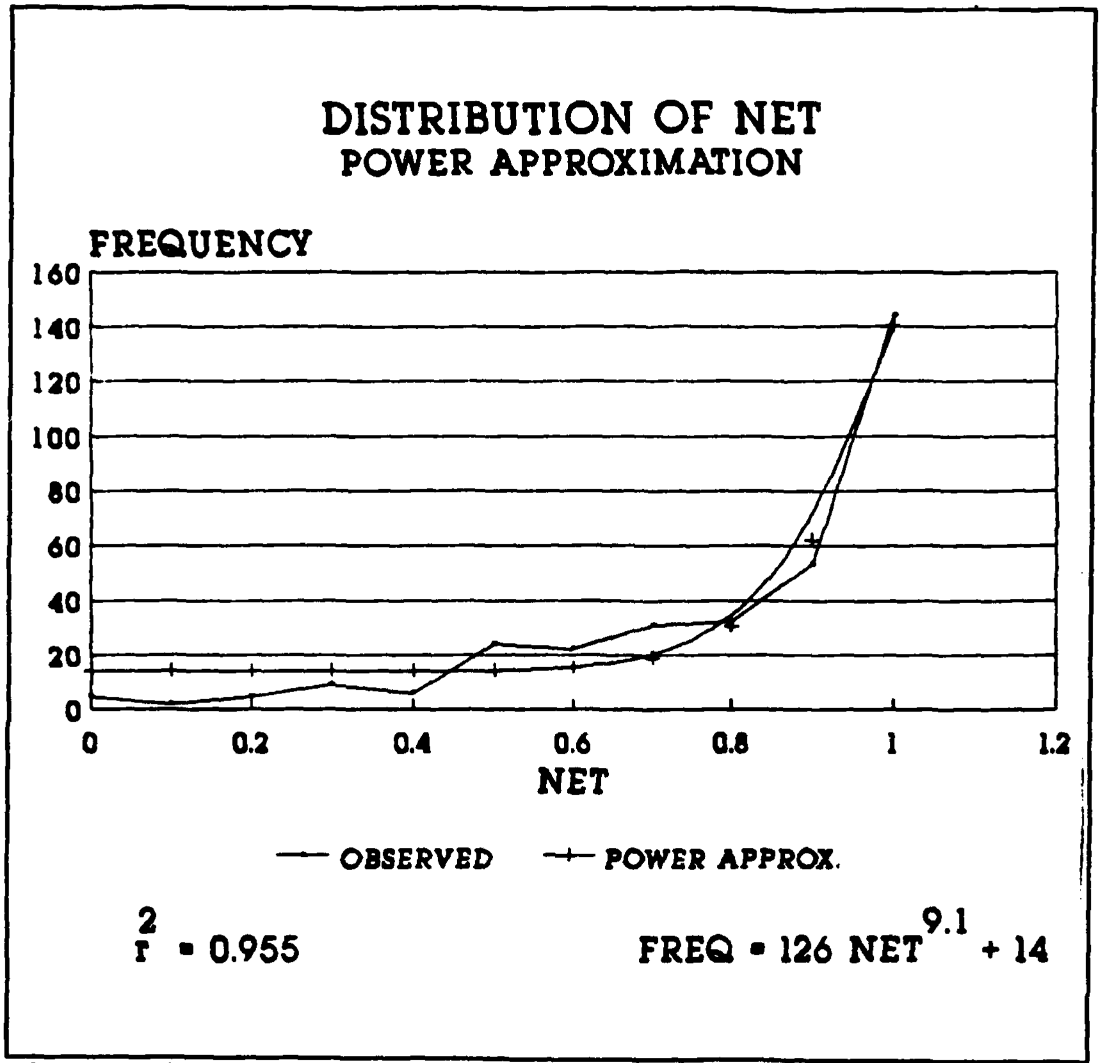

Figure 14 Net Approximation

Descriptive Statistics:

N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN
333	0.8110	0.9189	0.8374	0.2372	0.0130

MIN	MAX	Q1	Q3	AGGNET*
0.0000	1.0000	0.6705	1.0000	0.859

(* computed using total issues and referrals)

Figure 15 Summary of NET, Total Six Months

V. ANALYSIS

A. COMPARISON OF LEADTIME FORECASTED AND LEADTIME OBSERVED

Linear regression of LTO as a function of LTF yielded this equation:

$$LTO = 0.055 + 1.12\ LTF$$

However, the value of "r^2" for this equation was only 0.061 and the correlation of LTO to LTF was only 0.248. The low values of "r^2" and the correlation constant implied that LTF was a poor predictor of subsequent LTO. Figures 16 and 17 provide a scatter plot of LTO versus LTF with the regression equation superimposed and descriptive statistics of each for comparison. Note that in comparing the mean values to the corresponding medians, LTF was skewed very little while LTO was skewed significantly. Also, the standard deviation of LTF was only 0.3372 while LTO's was 1.5252. The arbitrary limiting of LTF to two months (discussed in Chapter III above) limited 25 NSNs, or 7.5% of the sample.

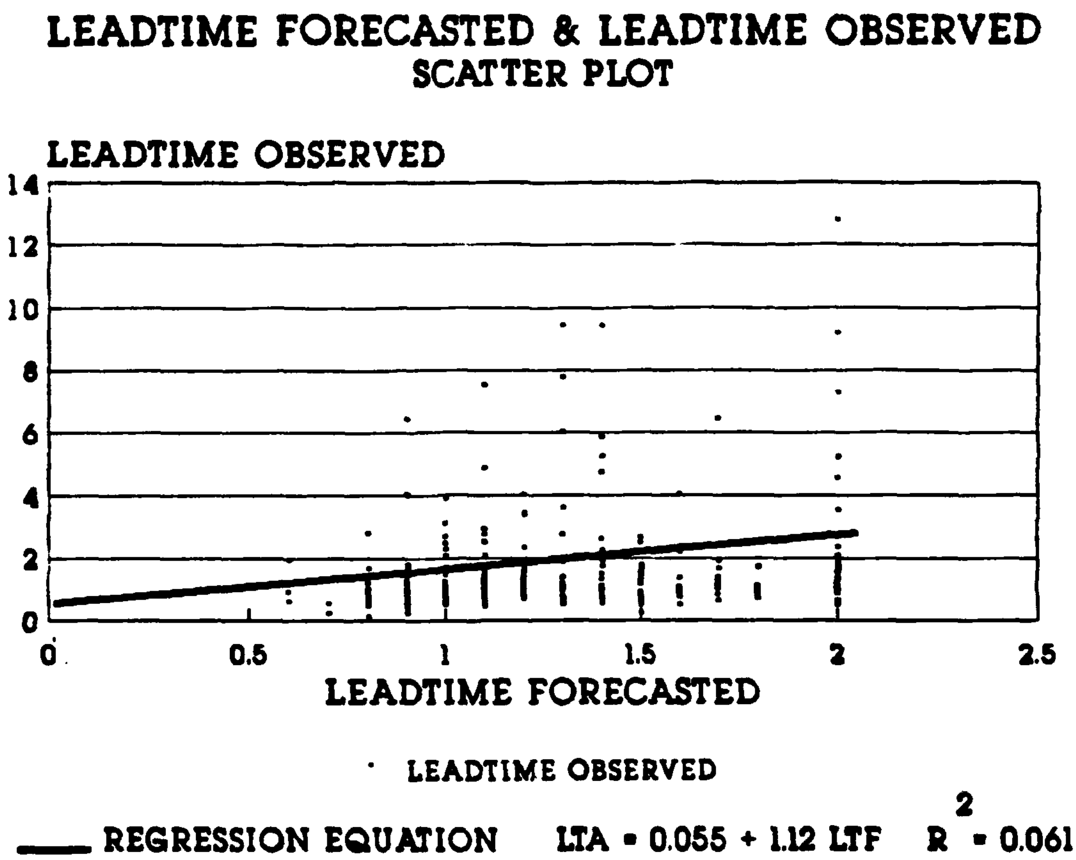

Figure 16 Observed versus Forecasted Leadtime Plot

	N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN
LTF	333	1.2468	1.2000	1.2334	0.3372	0.0185
LTO	333	1.4540	1.0000	1.2028	1.5252	0.0836

	MIN	MAX	Q1	Q3
LTF	0.4000	2.0000	1.0000	1.4000
LTO	0.1000	12.7667	0.7333	1.5000

Correlation of LTO and LTF = 0.248

Figure 17 Leadtime Observed and Leadtime Forecasted

B. ANALYSIS OF NET EFFECTIVENESS WITH TIME

The research question analyzed here was could a statistically significant trend in NET with respect to time be found. At a 95% confidence level only the first month after the dates of the requisitions had a statistically significant different mean. Figure 18 contains descriptive statistics and an analysis of variance for the six samples, measuring months of time beginning with the first month after the dates of the requisitions. As shown by the analysis of variance in Figure 18, all means except the first month were within the 95% confidence interval for the other samples. NET for month one was significantly less than NETs for all other months. There was insufficient evidence to claim that the means for months two through six were different or that a trend existed for those months.

C. REGRESSION OF NET EFFECTIVENESS WITH LEADTIME

Linear regression techniques applied to NET versus LTF or LTO yielded very poor results. Figures 19 and 20 provide scatter plots of raw NET versus LTF and LTO with the linear regression equations superimposed. The values of "r^2" were very low 0.012 and 0.070 respectively. The poor quality of the regression equations led the researcher to consider other analytical methods as presented in the following sections.

	N	N*	MEAN	MEDIAN	TRMEAN	STDEV
1st	282	51	0.7889	1.0000	0.8208	0.3329
2nd	264	69	0.8330	1.0000	0.8694	0.3022
3rd	245	88	0.8514	1.0000	0.8896	0.2880
4th	220	113	0.8525	1.0000	0.8898	0.2836
5th	226	107	0.8503	1.0000	0.8881	0.2853
6th	219	114	0.8491	1.0000	0.8881	0.2890

	SEMEAN	MIN	MAX	Q1	Q3
1st	0.0198	0.0000	1.0000	0.6670	1.0000
2nd	0.0186	0.0000	1.0000	0.7500	1.0000
3rd	0.0184	0.0000	1.0000	0.8785	1.0000
4th	0.0191	0.0000	1.0000	0.8570	1.0000
5th	0.0190	0.0000	1.0000	0.8000	1.0000
6th	0.0195	0.0000	1.0000	0.8000	1.0000

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F	p
FACTOR	5	0.8289	0.1658	1.86	0.099
ERROR	1450	129.5242	0.0893		
TOTAL	1455	130.3531			

```
                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                    BASED ON POOLED STDEV
LEVEL  MEAN    --+---------+---------+---------+----
1st    0.7889  (--------*--------)
2nd    0.8330            (--------*--------)
3rd    0.8514                (---------*--------)
4th    0.8525                (---------*---------)
5th    0.8503                (---------*--------)
6th    0.8491               (---------*---------)
               --+---------+---------+---------+----
               0.760     0.800     0.840     0.880
```

Figure 18 Analysis of Net Effectiveness with Time

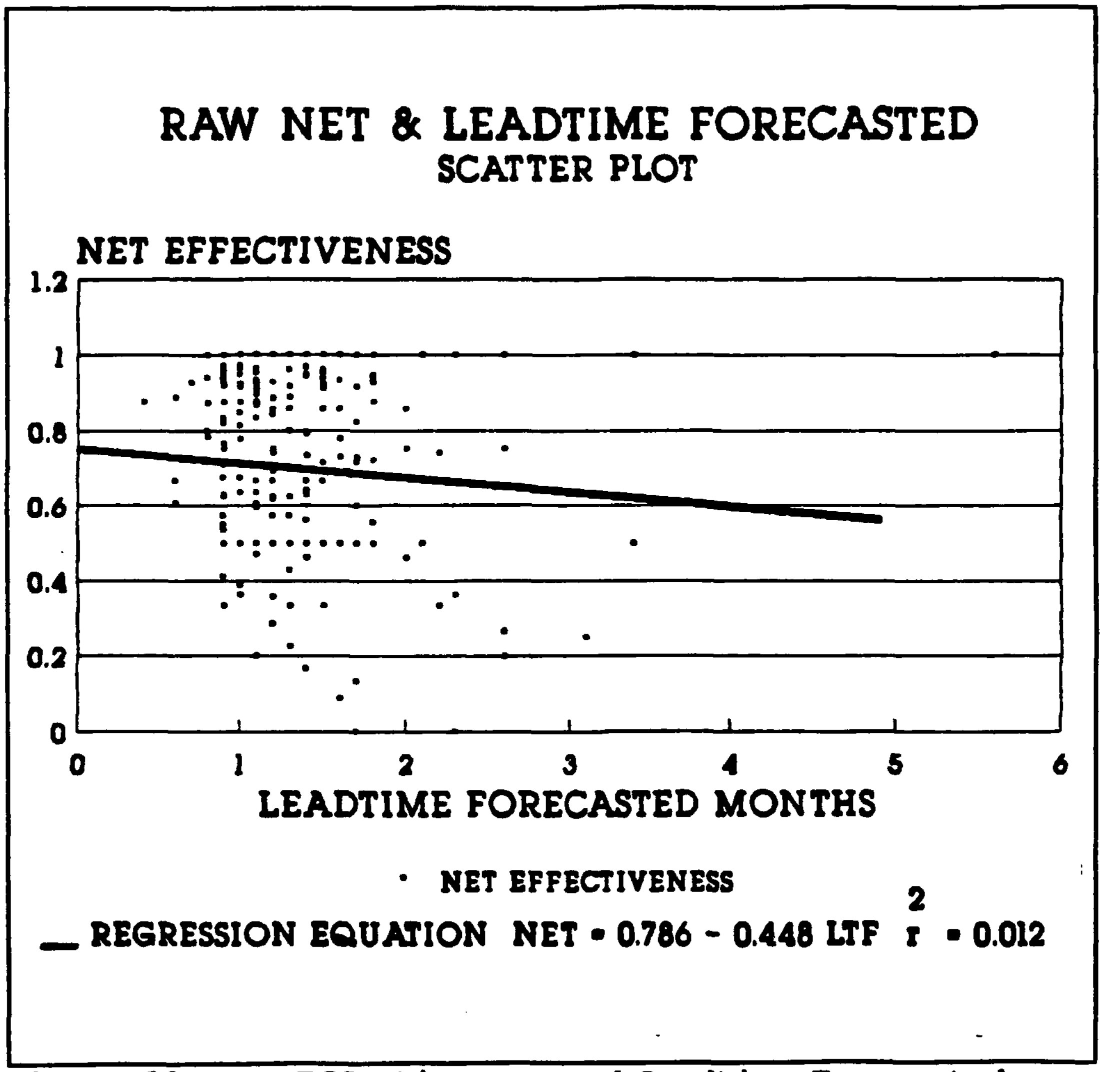

Figure 19 Net Effectiveness and Leadtime Forecasted

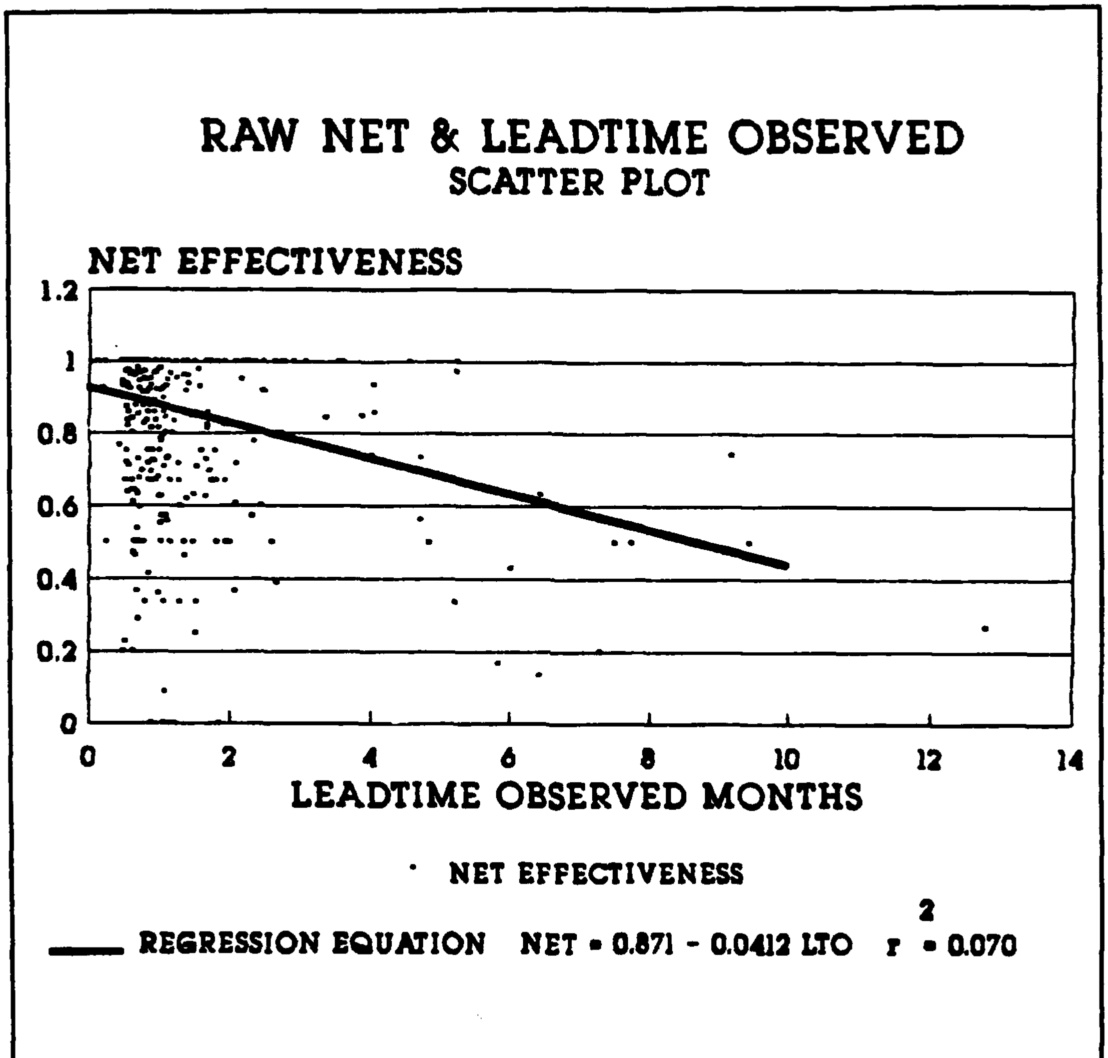

Figure 20 Net Effectiveness and Leadtime Observed

D. REGRESSION OF NET EFFECTIVENESS WITH LEADTIME INDEX

The next analytical step was to regress NET as a function of LT INDEX. Again, linear regression yielded only poor results. Figure 21 provides a scatter plot of NET versus LT INDEX with the linear regression equation superimposed. The value of "r^2" was a very low 0.041.

E. BINOMIAL TRANSFORMATION OF RAW NET DATA

A useful tool for inventory managers would be knowing what contribution an individual NSN was making toward achieving a given aggregate goal for NET. The binomial probability distribution provided a means to quantify this contribution. During the time of this study, NSC Oakland's aggregate goal for NET was 85%. The following steps describe the procedure used:

- Assign a probability value of "1" for each data point having NET greater than or equal to 0.85.
- Assign a probability value of "0" for each data point having NET less than 0.85.
- For each month of LTF, LTO, or each unit value of LT INDEX, find the expected probability during that month or unit of leadtime index.
- Plot the expected probability values as a function of LTF, LTO, or LT INDEX and perform regression analysis.

This procedure predicted the probability that, given LTF, LTO, or LT INDEX, an NSN would have a NET greater than or equal to 0.85.

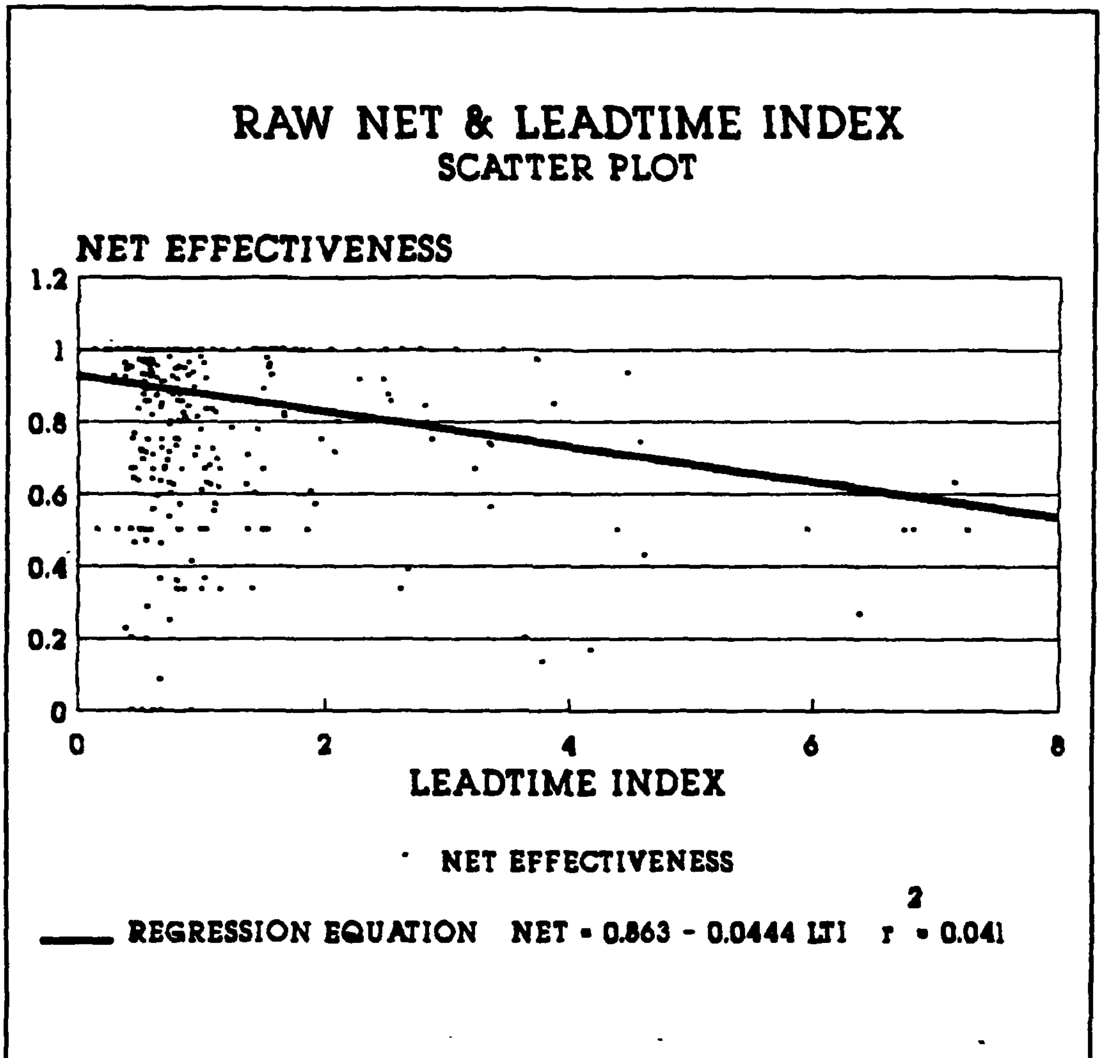

Figure 21 Net Effectiveness and Leadtime Index

F. REGRESSION OF TRANSFORMED NET WITH LEADTIME FORECASTED

Figure 22 provides a plot of the probability that NET was greater than or equal to 0.85 versus LTF. As described in Section E above, the expected probability value of all data points in the interval from greater than or equal to the lower bound but less than the upper bound for each month of LTF was plotted versus the corresponding month of LTF. This plot omitted two outlying data points (out of 333 total) at LTF equals 5.5 months. This function was from the normal family of functions and had a sin term to dampen the amplitude. The value of "r^2" for this function was 0.866. The chi-square test for this approximation indicated that with alpha equal to 5% there was not sufficient evidence to reject the null hypothesis that the function approximated the actual data.

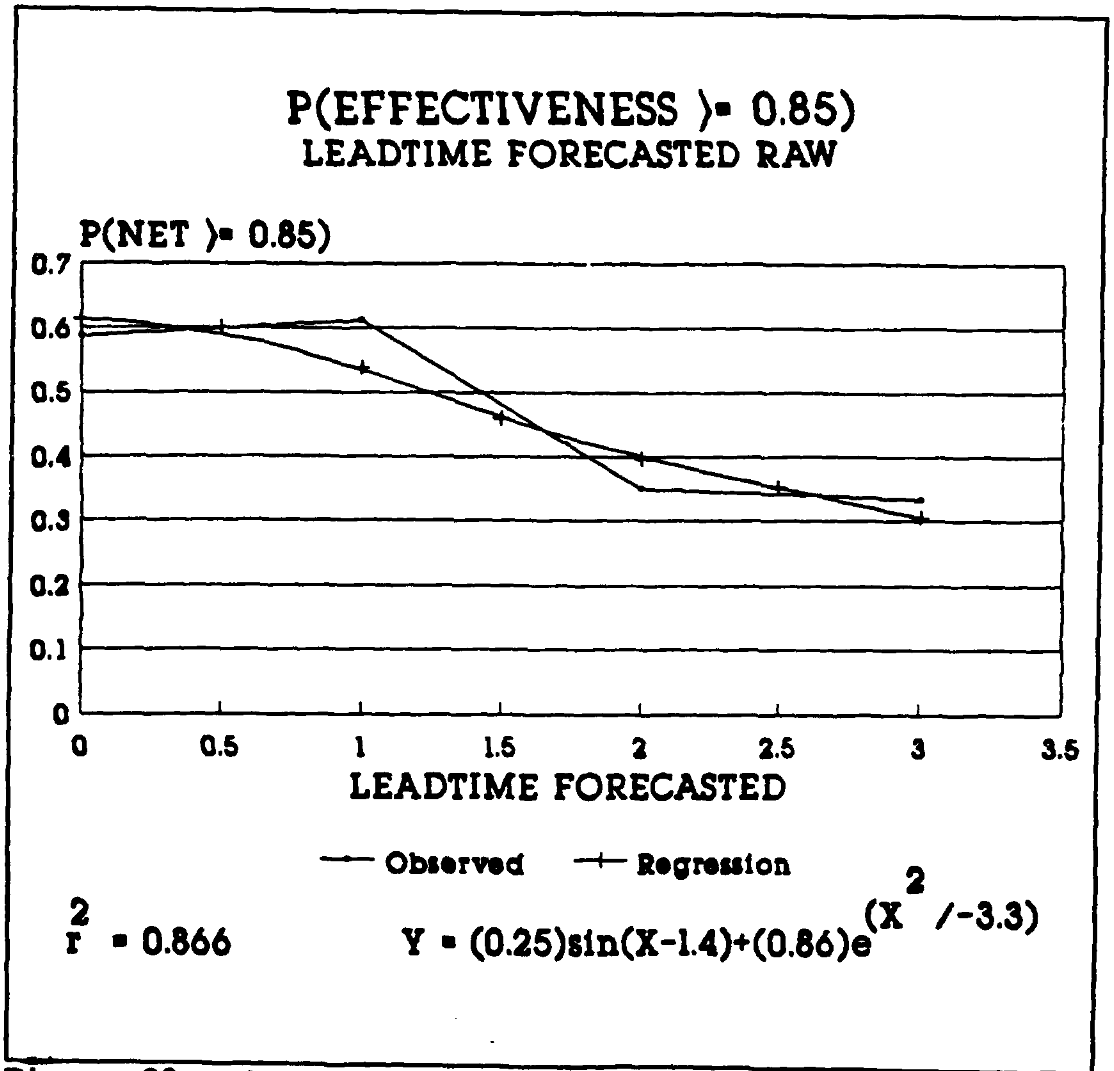

Figure 22 P(Net >= 0.85) & Leadtime Forecasted

G. REGRESSION OF TRANSFORMED NET WITH LEADTIME OBSERVED

Figure 23 provides a plot of the probability that NET was greater than or equal to 0.85 versus LTO. The normal family regression equation shown on Figure 23 fit the data points with a value of "r^2" of 0.89. The chi-square test for this approximation indicated that with alpha equal to 5% there was not sufficient evidence to reject the null hypothesis that the function approximated the actual data.

H. REGRESSION OF TRANSFORMED NET WITH LEADTIME INDEX

Using the normal family of distributions to transform LT INDEX provided an even better regression equation than for LTF or LTO. Figure 24 shows the equation with a plot of the observed and forecasted probabilities versus LT INDEX. The value of "r^2" for P(NET >= 0.85) was an excellent 0.943. The chi-square test for this approximation indicated that with alpha equal to 5% there was not sufficient evidence to reject the null hypothesis that the function approximated the actual data. For this sample of 333 NSNs, if LT INDEX was two (ie., LTO was twice LTF), then there was a 50% probability that NET for that NSN was greater than or equal to 0.85. For LT INDEX greater than two, the probability was less than 50%. For LT INDEX less than two, the it was greater than 50%.

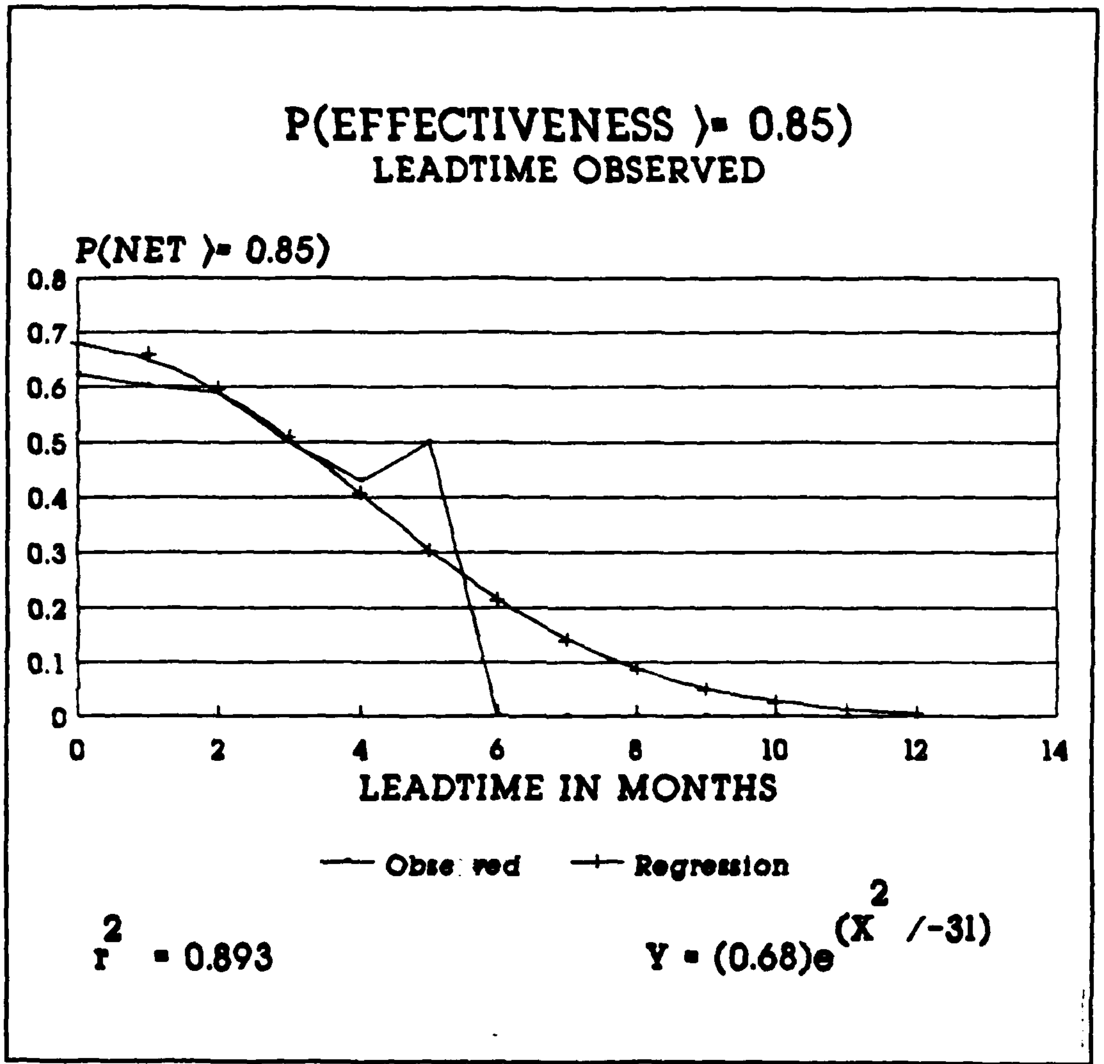

Figure 23 P(Net >= 0.85) & Leadtime Observed

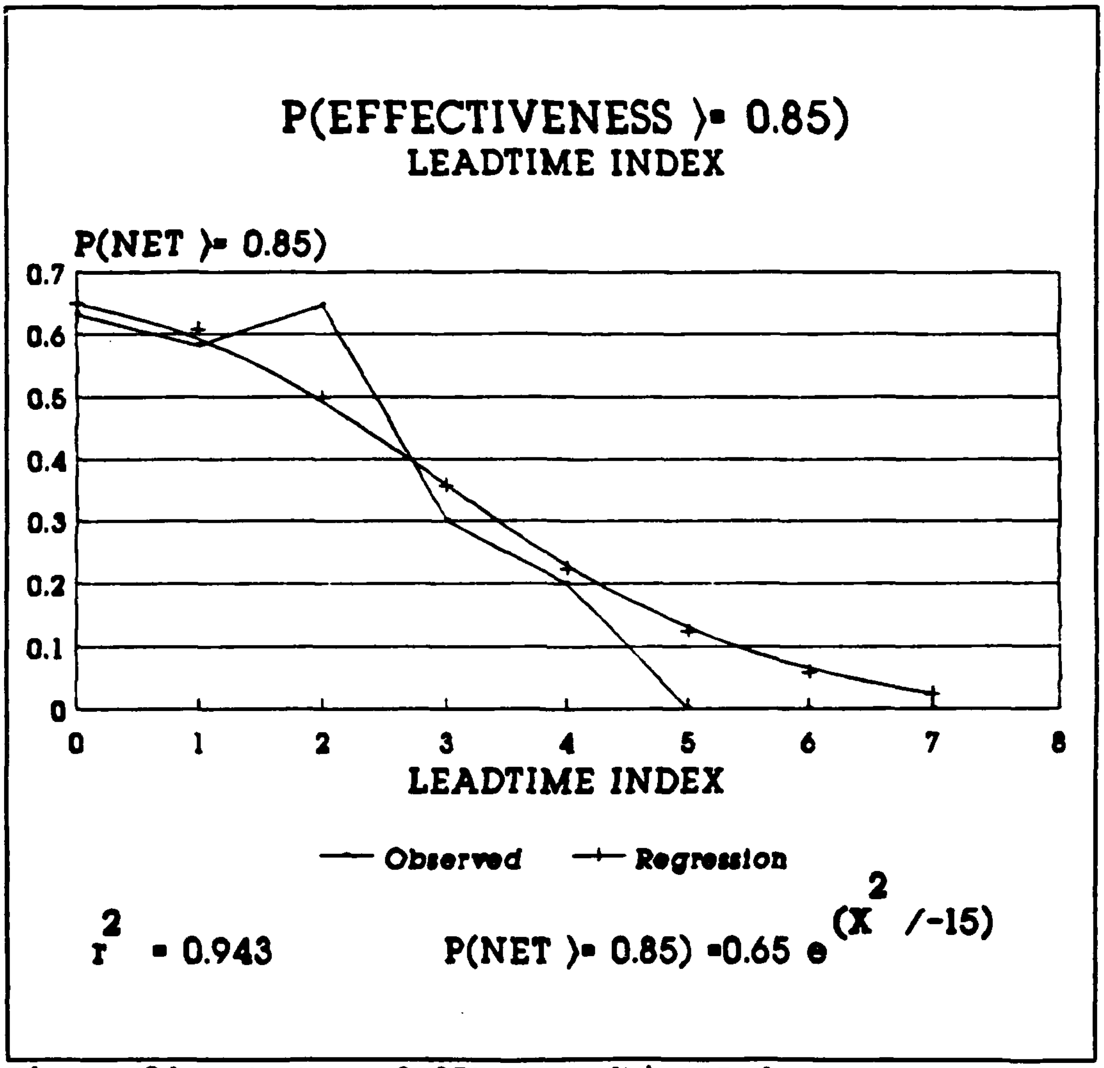

Figure 24 P(Net >= 0.85) & Leadtime Index

VI. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY OF RESEARCH QUESTIONS

1. Relationship of Leadtime to Net Effectiveness

The best values of "r^2" for a simple linear regression equation of NET as a function of LTF or LTO were only 0.012 and 0.070 respectively. However, binomial transformation techniques yielded values of "r^2" of 0.866 and 0.893 for the probabilities that NET was greater than or equal to 0.85 as a function of LTF or LTO (see Figures 22 and 23). Performing the same transformation technique for NET as a function of LT INDEX yielded a regression equation with a value of "r^2" of 0.943 (see Figure 24).

2. Computation of Leadtime Forecasted

NSC Oakland computed LTF with UADPS-SP program D-UB39, "Quarterly and Random Demand Update and Levels Computation". This program applied exponential smoothing to the previous LTF and the average of the current quarter's LTO to compute the forecast for the next quarter:

$$LTF_{n+1} = (0.8 \text{ X } LTF_n) + (0.2 \text{ X AVER } LTO_n)$$

Additionally, program D-UB39 constrained LTF to less than or equal to two months for continental U.S. activities including NSC Oakland (see Chapter III, Section C, Subsection 2). For

this thesis 25 (7.5%) of the NSNs studied had a constrained LTF.

3. Precision of Forecasted to Observed Leadtime

LTF poorly predicted actual LTO. Correlation of LTO and LTF yielded a low correlation value of 0.248 (see Chapter V, Section A).

4. Distributions of Leadtimes and Net Effectiveness

Members of the gamma family fit LTF, LTO, and LT INDEX well with values of "r^2" 0.911, 0.997, 0.920 respectively (see Figures 2, 4, and 6). The power frequency distribution best fit NET with a value of "r^2" of 0.955 (see Figure 14).

5. Relationship of Net Effectiveness and Time

Analysis of variance techniques at the 95% confidence level yielded a statistically significant lower NET for the first month after the dates of the replenishment requisitions (see Chapter V, Section B). NETs for the second through the sixth months were not significantly different from each other.

B. CONCLUSIONS

This thesis concluded that:

- LTF predicted well the probability that a particular NSN would achieve a given level of NET following replenishment.
- LTO and LT INDEX correlated well with the probability that a particular NSN would achieve a given level of NET following replenishment.
- Values of LTF greater than 1.4 months predicted a probability of at least 0.50 that NET would not achieve 0.85 for that NSN.

- Values of LTO greater than 3.0 months correlated with a probability of at least 0.50 that NET would not achieve 0.85 for that NSN.

- Values of LT INDEX greater than 2.0 correlated with a probability of at least 0.50 that NET would not achieve 0.85 for that NSN.

- LTO and LT INDEX were poor predictors of the actual value of subsequent NET.

- LTF was a poor predictor of subsequent LTO.

- The first month after the date of replenishment had a statistically significant lower NET than the second through sixth months.

C. RECOMMENDATIONS

This thesis recommends that:

- Inventory managers should consider additional safety stock and/or increased monitoring of replenishment requisitions for NSNs with LTF greater than or equal to 1.4 months.

- Inventory managers should monitor LTO and LT INDEX, expediting due-in material to keep values of LTO and LT INDEX from exceeding 3.0 months and 2.0 respectively.

- Additional research is indicated to develop better models to predict NET and LTO as functions of LTF.

- Additional research is indicated to determine if the degradation of NET during the first month after replenishment requisitioning could be negated.

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